MOLTEN CARBONATE FUEL CELL PRODUCT DESIGN IMPROVEMENT

SEMI-ANNUAL TECHNICAL PROGRESS REPORT
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ABSTRACT

The ongoing program is designed to advance the carbonate fuel cell technology from full-size proof-of-concept field test to the commercial design. DOE has been funding Direct FuelCell® (DFC®) development at FuelCell Energy, Inc. (FCE) for stationary power plant applications. The program efforts are focused on technology and system optimization for cost reduction leading to commercial design development and prototype system field trials. FCE, Danbury, CT, is a world-recognized leader for the development and commercialization of high efficiency fuel cells that can generate clean electricity at power stations or in distributed locations near the customer, including hospitals, schools, universities, hotels and other commercial and industrial applications.

FuelCell Energy has designed three different fuel cell power plant models (DFC300, DFC1500 and DFC3000). FCE's power plants are based on its patented Direct FuelCell technology, where the fuel is directly fed to fuel cell and hydrogen is generated internally. These power plants offer significant advantages compared to existing power generation technologies – higher fuel efficiency, significantly lower emissions, quieter operation, flexible siting and permitting requirements, scalability and potentially lower operating costs. Also, the exhaust heat by-product can be used for cogeneration applications such as high-pressure steam, district heating, and air conditioning. Several FCE sub-megawatt power plants are currently operating in Europe, Japan and the US. Because hydrogen is generated directly within the fuel cell module from readily available fuels such as natural gas and waste water treatment gas, DFC power plants are ready today and do not require the creation of a hydrogen infrastructure. Product improvement progress made during the reporting period in the areas of technology, manufacturing processes, cost reduction and balance of plant equipment designs is discussed in this report.

FCE's DFC products development has been carried out under a joint public-private effort with DOE being the major contributor. Current funding is primarily under a Cooperative Agreement with DOE.

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1.0 INTRODUCTION

The carbonate fuel cell promises highly efficient, cost-effective and environmentally superior power generation from pipeline natural gas, coal gas, biogas, and other gaseous and liquid fuels. FuelCell Energy, Inc. (FCE) has been engaged in the development of this unique technology, focusing on the development of the Direct FuelCell (DFC®). The DFC® design incorporates the unique internal reforming feature which allows utilization of a hydrocarbon fuel directly in the fuel cell without requiring any external reforming reactor and associated heat exchange equipment. This approach upgrades waste heat to chemical energy and thereby contributes to a higher overall conversion efficiency of fuel energy to electricity with low levels of environmental emissions. Among the internal reforming options, FuelCell Energy has selected the Indirect Internal Reforming (IIR) – Direct Internal Reforming (DIR) combination as its baseline design. The IIR-DIR combination allows reforming control (and thus cooling) over the entire cell area. This results in uniform cell temperature. In the IIR-DIR stack, a reforming unit (RU) is placed between groups of fuel cells. The hydrocarbon fuel is first fed into the RU where it is reformed partially to hydrogen and carbon monoxide fuel using heat produced by the fuel cell electrochemical reactions. The reformed gases are then fed to the DIR chamber, where the residual fuel is reformed simultaneously with the electrochemical fuel cell reactions.

FuelCell Energy has designed submegawatt (DFC300A) and megawatt (DFC1500 and DFC3000) class fuel cell power plants based on its DFC® technology. These are standardized, packaged power plants operating on natural gas or other hydrocarbon-containing fuels. The power plant design also includes other fuel processing options to allow multiple fuel applications. These power plants, which can be shop-fabricated and sited near the user, are ideally suited for distributed power generation, industrial cogeneration, marine applications and uninterrupted power for military bases.

FuelCell Energy operated a 1.8 MW plant at a utility site in 1996-97. This proof-of-concept power plant demonstrated high efficiency, low emissions, reactive power control, and unattended operation capabilities. Drawing on the manufacture, field test, and post-test experience of the full-size power plant, FuelCell Energy launched the Product Design Improvement (PDI) program sponsored by government and the private-sector cost-share. The PDI efforts are focused on technology and system optimization for cost reduction, commercial design development, and prototype system field trials. Major accomplishments in these areas during the 2nd half of 2003 are discussed in the report.

2.0 EXECUTIVE SUMMARY

Under the cooperative agreement DE-FC21-95MC31184 with DOE/NETL, FuelCell Energy, Inc. has been developing its DFC® technology for stationary power plants. The objective of the program is to develop and demonstrate a cost-effective, market responsive DFC® power plant design(s) and make it ready for commercial entry. Significant progress has been achieved during the reporting period, June 2003 through December 2003, as highlighted below.

- Cell and stack designs are being further refined to improve performance, reduce cost and enhance endurance capability.

  - Advanced cathodes being developed have shown 10-15 mV performance improvement over the baseline cathodes in single cell tests. Further evaluation in stack tests is planned.

  - Advanced manifold and gasket designs have improved gas-seal efficiency by more than 100% in subscale stack tests.

- Cell matrix quality and tape casting process yield were improved significantly by monitoring and controlling raw material quality, process environment and key parameters. Improvements in packing density and matrix strength have contributed to this manufacturing process enhancement.

- During the second phase of the full-size Stack FA-100-3 test, rapid load return capability of the stack, upon grid disturbance and subsequent transfer to island mode of operation, was successfully demonstrated with a fast load ramp rate of up to 150 A/min to 90% of rated load (less than 5 min ramp duration).

  In other tests, operation of Stack FA-100-3 in island mode with 10-15% load variation lasting up to 24h was verified. For larger load fluctuations capability, application of an AC load bank as a load leveling dissipater was also initiated.

- A MW-class stack module was performance tested up to rated load in a fully integrated power plant at Torrington, verifying the stack and module designs.

- Progress in balance-of-plant equipment technology improvement and cost reduction was also continued.

  - Evaluation of advanced sorbents for natural gas desulfurization, in 400 kW facility, has shown that a new design extended bed life to 6-8 times that of the baseline sorbent. The promising design has been implemented in the product power plants.

  - Evaluation of DC-to-AC inverters from different vendors, in the 400 kW facility, has resulted in 3 vendors being qualified for supplying inverters for FCE products and an inverter cost reduction of ~50%.

- Value engineering activities for power plant cost reduction have resulted in ~15% reduction for FCE's DFC300 sub-MW power plant, during the reporting period.

3.0 EXPERIMENTAL

The program involves manufacturing process improvements, cell component development, stack design and balance-of-plant (BOP) equipment development. Various tests such as simulated out-of-cell property characterization and button cell, single cell, subscale stack and full-size stack tests were used to support these developments. FCE has five button cell and eighteen single cell test stands, four subscale stack and one full-size stack test facilities. The button cell and single cell test stands are used for active component development. The subscale stack test stations are used for cell design and endurance evaluation. The full-size stack facility is used for stack design, non-repeat hardware design and BOP equipment design evaluation. These test tools were used routinely throughout the execution of the program. Additional experimental details are provided along with the relevant test results discussed under “Results and Discussions” section of the report.

4.0 RESULTS AND DISCUSSIONS

Progress was continued in stack and BOP equipment technology improvement and cost reduction areas (see Ref. 1 to 4 for previous progress reports). Key program accomplishments during the second half of Year 2003 are discussed below.

Technology Improvement

FCE is developing fuel cell power plants based on the company's DFC® technology. Current program is focused on improving components design for product output uprate and endurance enhancement. The specific activities being pursued for achieving these goals and the progress achieved in these areas are discussed next.

Alternate Cathode Development: Cathode polarization reduction offers an opportunity to further improve the cell conversion efficiency. FCE has developed advanced cathodes. These cathodes tested in button and single cells (3 cm^2 and 250 cm^2, respectively) showed higher (10-15 mV, at 160 mA/cm^2 current density and standard test conditions) performance than the baseline cathodes. This improvement would translate to ~10% power output uprate. In addition, these cathodes extended the life of single cells by more than 35%. Evaluation of the advanced cathodes in stacks is planned.

Advanced Cathode Current Collectors for Endurance Enhancement: Alternate cathode current collectors (CCC) are being developed for longer cell life and performance improvement. Two protected-CCC materials (A and B) were selected for investigation. Single cell tests of these CCCs exhibited significantly less electrolyte creepage and corrosion (Figures 1 and 2) compared to the baseline CCC. The electrolyte loss rate was reduced by >50%. Recent single-cell tests show that the protected-CCC also improves cell performance. Endurance of the cells has also been significantly improved as evident from cell resistance stability observed during tests and post-test analysis results. Efforts now are focused on further optimizing this process and process scale-up. Verification testing in a full-size stack is planned for 2004-2005.

Reforming Unit Design Improvement: The Direct Fuel Cell (DFC®) developed by FuelCell Energy uses a highly efficient thermal management scheme. Endothermic internal reforming reaction is used to remove heat from the DFC® stack. Thermal uniformity is achieved in the stack by controlling the distribution of the reforming reaction in the Reformer Unit (RU) and the Direct Internal Reformer (DIR). Improvement in thermal uniformity will increase durability and enable increase in power output.

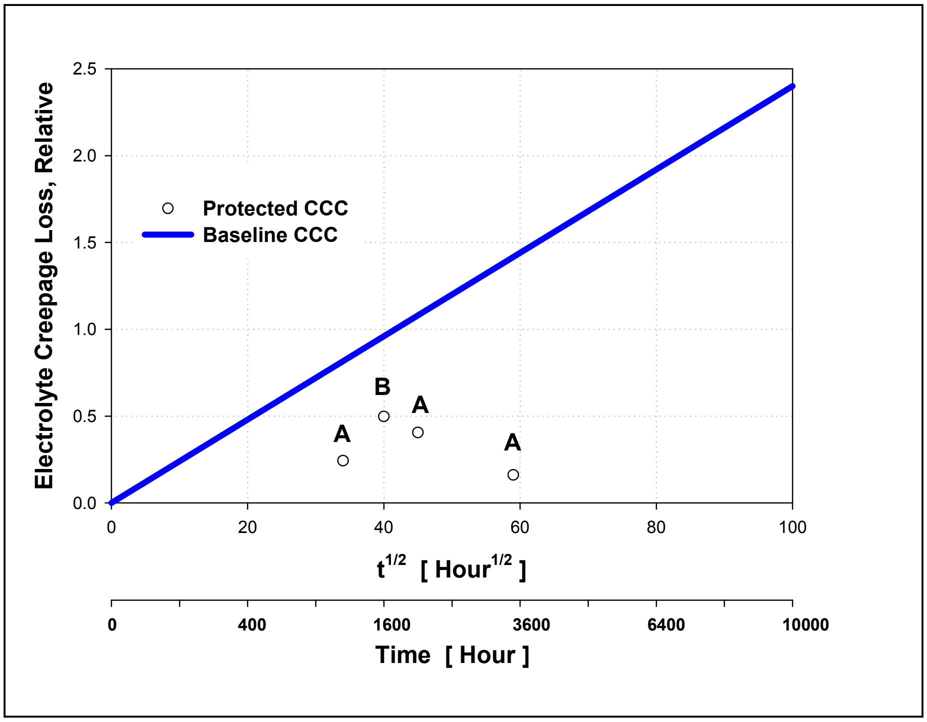

Figure 1. ELECTROLYTE CREEPAGE REDUCTION OFFERED BY PROTECTED-CCC (MATERIALS A AND B):
More Than 50% Reduction Observed

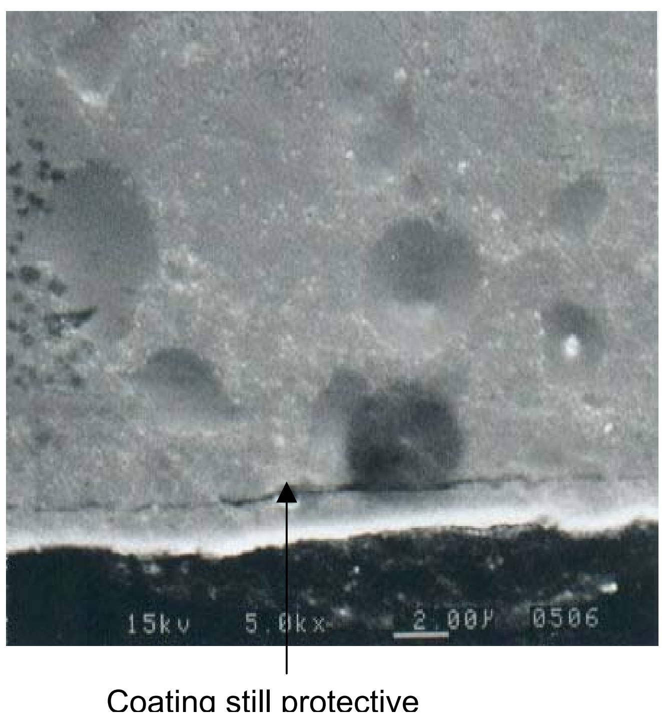

Figure 2. POST-TEST MICRO-PHOTOGRAPH OF PROTECTED-CCC MATERIAL A:
Virtually No Corrosion of Substrate After 2,000h In-cell Testing

A comprehensive computational fluid dynamics (CFD) model was developed earlier under this effort (using commercial software FLUENT) to predict the temperature, current, and gas flow distribution in the DFC stack. For given inputs of flow, temperature and composition of fuel and oxidant inlet streams, and the total stack current (or current density); the model predicts the stack voltage and 3D distributions of temperature and current. In addition, the model also predicts the temperature, flow and compositional variations of different gas streams (anode, cathode and reforming unit fluid flow) inside the stack. The model has been validated using experimental data from 30-cell subscale stacks.

The model has been used to study different reforming unit (RU) designs in the second half of year 2003. An improvement in average cell performance (5 mV) and a reduction in thermal gradient were achieved through RU design improvements. Table 1 shows the improvement obtained in the 30-cell Stack FA-20-9 compared to baseline design (Stack FA-20-8).

Table 1. THERMAL IMPROVEMENT ACHIEVED BY RU DESIGN IMPROVEMENTS

Operation/Performance Parameter	New Design (FA-20-10; RU-16E)	FA-20-9, RU-16C	FA-20-8, RU-16a (baseline)
Run hours	Expected @ 1000h	1248	1339
i (mA/cm^2)	140	140	140
Uf(GC)	75%	72.6%	73.4%
Volts	0.756	0.760	0.755
Tavg (°C)	640	644	642
ΔT (°C)	115	124	127

An improved RU design, RU16-E was also developed and will be tested in the 30-cell stack FA-20-10. Model predicts that new design will improve the efficiency (higher fuel utilization) and also reduce thermal gradients compared to previous designs. Figures 3 and 4 compare the measured and the predicted temperature distributions for Stacks FA-20-8 and FA-20-10, respectively. The data indicate Stack FA-20-10 will have ~10% lower thermal gradient.

Manufacturing Process Improvement/Cost Reduction

Manufacturing process activities continued to improve product quality and reduce cost. The cell matrix quality and tape casting process yield have been found to be sensitive to the raw material characteristics, environment humidity and process parameters such as milling time, drying time, slurry viscosity, etc. Changes in these affect packing density and matrix structural properties. By closely monitoring incoming raw material for quality assurance, and controlling environment factors and the key process parameters, matrix properties can be controlled to the desired levels. Good correlations and understanding of the effects of various parameters associated with the process have been developed at FCE. Process enhancements were identified to improve the packing density and matrix strength. As a result, matrix quality and yield have been improved significantly.

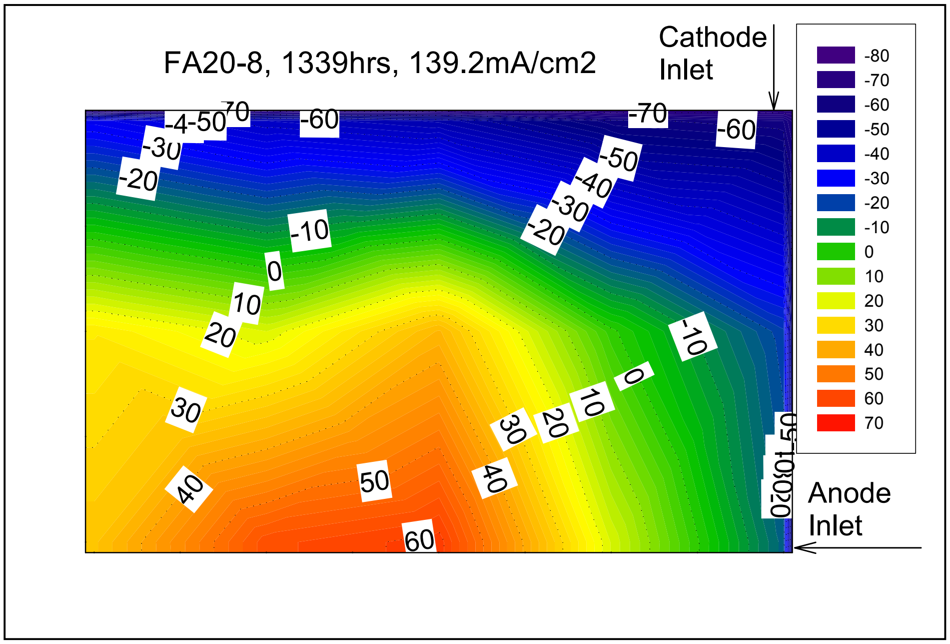

Figure 3. TEMPERATURE DISTRIBUTION (RELATIVE SCALE) MEASURED IN STACK FA-20-8:
Baseline RU Design

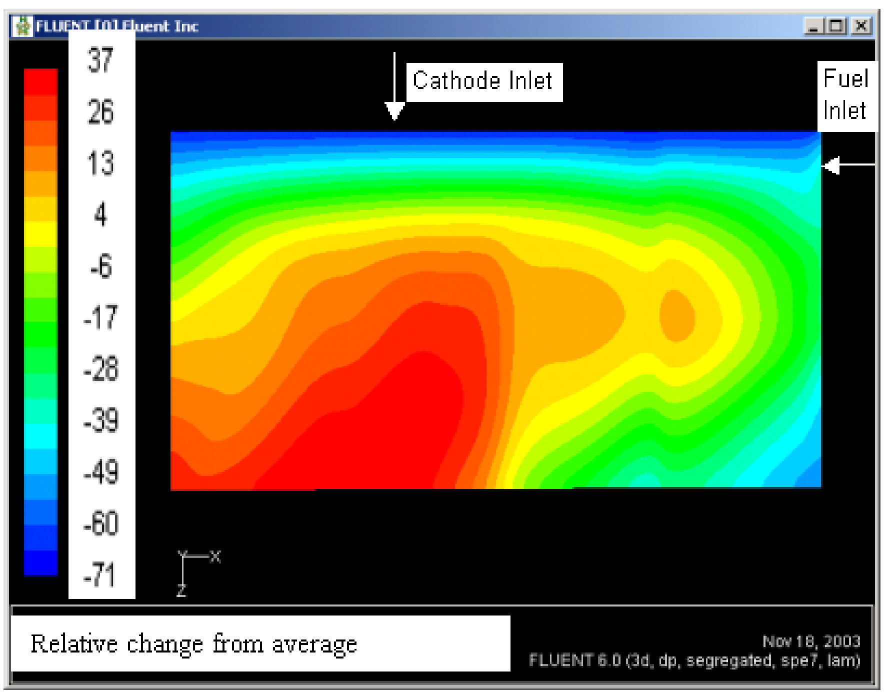

Figure 4. TEMPERATURE DISTRIBUTION PREDICTED WITH RU16E DESIGN:
To be Tested in 30-cell Stack FA-20-10

An attaching aid is used for holding direct internal reforming (DIR) catalyst in the anode side current collector. Quantity used has been reduced by 50% leading to a cost reduction and reduction of organic burn-outs during the conditioning step. This process has been recommended for its implementation in product stacks after its verification testing in technology stacks.

Stack Test Activities

Stack test activities included continuation of full-height Stack FA-100-3 test and some subscale stack tests.

Full-Height Stack Test: Full-size Stack FA-100-3 (360 cells) was restarted following a thermal cycle after 2,600h of operation for evaluation of an improved gasket system. The stack showed no effects of the thermal cycle on performance. The performance at 120 mA/cm^2 was equivalent to, or slightly better than pre-thermal cycle performance. So far the stack has operated for 3,500h and generated 540 MW-h of electricity.

The full suit of important operations to transfer to and operate in island mode have been demonstrated with full-size Stack FA-100-3: a) successful transfer from grid-connect (GC) to island or stand alone (SA) mode and back to GC, b) stable long-term operation in island mode, c) use of AC load bank "load leveler" on the critical bus to maintain the stack at constant load as it transfers from GC to SA, and d) rapid load recovery to previous GC load after short-term operation at low SA load (e.g., due to short-term grid disruption). The commercial goal of the island operations is to have products that will provide uninterrupted power to the customer's critical bus in the event of a grid disruption.

FCE has been working with several inverter manufacturers to improve the transfers from GC to SA mode and back to GC, with progress in the smoothness of the transfer in terms of critical bus AC voltage deviation and fuel cell DC current perturbations. To speed this development, detection devices were installed in the 400 kW facility to closely monitor electrical occurrences of the grid, AC output of the inverter and the DC output from the fuel cell stack. The equipment continuously monitors voltage and current for all three AC phases, and the same for the fuel cell DC output. "Triggers" are set to capture events. By analyzing the electrical transactions data, the reasons for unsuccessful transfers can be identified and acted upon.

Load following capability of the 400 kW facility has been demonstrated with Stack FA-100-3, with numerous episodes of SA operations lasting from a few seconds to 24h. After the successful transfer by the inverter from GC to SA mode, several process parameters must rapidly adjust to the new and changing SA load: fuel flow, water flow, and process temperatures. The SA operation demonstration has been successful in the safe and steady operation of the DFC® plant with SA load variations of 10 to 15%.

Certain customers of DFC® products prefer to have the capability for suddenly increasing their customer critical bus (CCB) load, while the unit is in SA mode, by more than the 10-15% increase allowed for the fuel cell stack. For these customers the 400 kW facility has demonstrated the aspects of a load leveling dissipater. The load leveler was an AC load bank on the critical bus that rapidly changed load to counter balance the changes to the CCB load. This way the fuel cell stack was maintained within its load variation limit despite the large, instantaneous fluctuations on the CCB. So far the load leveler demonstration has shown the ability to transition from GC to SA while maintaining high stack power despite very low CCB load. The goals of the next phase are to demonstrate rapid start of the AC load bank fan upon transition to SA mode, and rapid control of the AC load bank to counter balance large load fluctuations on the critical bus within a few seconds.

Stack FA-100-3 test has also confirmed that DFC® stacks can be rapidly returned to high load after a short-term drop to low load. This is applicable to the product when it is operating on high load, and due to a momentary grid outage is brought to a low load on the SA critical bus. Upon the grid return, full load can be restored within minutes. Several tests were conducted where the grid outage was simulated from various load levels. The plant was brought to the critical bus supporting only the plant parasitic loads. Upon grid return the stack load was restored within a few minutes. The maximum stressed test was a drop from 120 mA/cm^2 (full-load) to 10 mA/cm^2 (facility parasitic or minimum critical bus load), hold for 1 minute, and ramp back to 110 mA/cm^2 (90% of the load) at 100 A/min (8 minute-ramp). The remaining ramp from 110 to 120 mA/cm^2 was conducted at a slower rate (3 A/min, 26 minutes). No stack issues were encountered. Stack voltages returned to pre-exercise values with no resulting lag or decay. A faster load ramp at 150 A/min was also demonstrated, bringing the stack from 20 to 110 mA/cm^2 in less than 5 minutes (Figure 5).

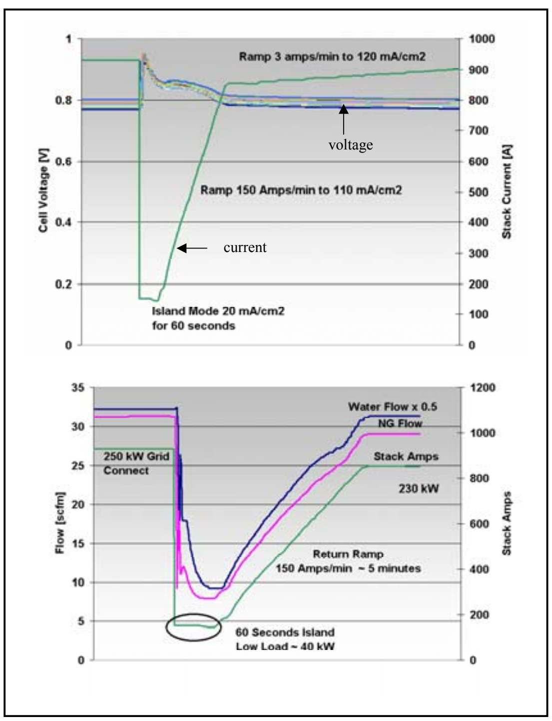

Figure 5. RESPONSE OF FULL-SIZE STACK FA-100-3 DURING ISLANDING AND SUBSEQUENT RAPID LOAD RECOVERY TEST:
Robustness of Full-size Stack Demonstrated

The full-size stack test was voluntarily interrupted for evaluation of a newly developed symmetric manifold retention system which also accompanies a new improved manifold and dielectric system design. Restart is planned early next year.

Subscale Stack Tests: Prototype subscale stacks containing 10-30 full-area cells are tested to verify the advanced cell and stack designs. Currently, four test facilities are in operations with stacks of 10-30 kW range. Calibration and debugging of the newly commissioned facility was completed in October 2003. This new facility is shown in Figure 6. Test status as of 12/31/03 is summarized in Table 2.

Figure 6. NEWLY-COMMISSIONED 30 kW STACK TEST FACILITY:
Shows a Subscale Stack in Operation

Table 2. TEST STATUS OF SUBSCALE STACKS

Facility	Stack	Stack Size	Test Objectives	Current Status
TF10kW	FA-5-10	10 cells with 1 reformer unit (RU)	• Electrolyte optimization for longer cell life	• 6,000h at 140 mA/cm^2
TF20kW	FA-15-1	22 cells with 3 Rus	• Improved gas-seal efficiency with compliant manifold gasket • Endurance testing to establish performance characteristics for high power operation	• 11,500h at 140 mA/cm^2, 70-72% fuel utilization (endurance operation)
TF30kW-1	FA-20-9	30 cells with 4 Rus	• Improved thermal management with RU	• 4,700h at 140 mA/cm^2, 71% fuel utilization
FA30kW-2	FA-15-2	22 cells with 3 RUs	• Improved gas-seal efficiency with advanced manifold system	• 1,000h at 100 mA/cm^2, 69% fuel utilization

Stack FA-5-10 was designed to study opportunities for extending stack life by optimal electrolyte management. For this purpose, two groups of cells with different electrolyte loadings were used to fabricate the stack. The cell group with lower electrolyte loading showed about 18 mV higher average cell voltage at the beginning of life, and only 5-8% faster performance decay during 6,000h of operation so far. This suggests that the electrolyte distribution in cell component is a primary factor controlling long-term operation of stack. It also implies that more than 6,000h of life extension is feasible with optimal electrolyte management. Stack FA-15-1 is currently in endurance operation mode at 140 mA/cm^2 with 72% fuel utilization. This long-term operation enabled evaluation of performance stability of the stack during high power operation. Overall performance decay rate at 140 mA/cm^2 with more than 71% fuel utilization was quite small and within the 2003 technology goal.

Manifold gas-seal efficiency of improved designs has been evaluated in several stacks (FA-15-1, FA-20-8, FA-20-9 and FA-15-2). Compared to the benchmark stack, FA-20-7, about 100% improvement in seal efficiency has been achieved by compliant gasket design with flexible shims as shown in Figure 7. Also an advanced manifold design with symmetric retention system, which was tested in the recent Stack FA-15-2, showed additional 50% reduction of leak rate at the beginning of life. Further evaluation in future stacks is planned.

In addition to the verification of reduced gas-seal leakage, a new reformer unit(RU) design was tested in Stack FA-20-9 for improved thermal management. Thermal profile in this stack was more uniform, and it significantly improved during the initial 2,500h of operation. As a result, the average cell voltage improved by 6-9 mV, which corresponds to about 6% power increase in a full-size stack. Protected-CCC tested in FA-20-9 also showed promising results. Further characterization is underway.

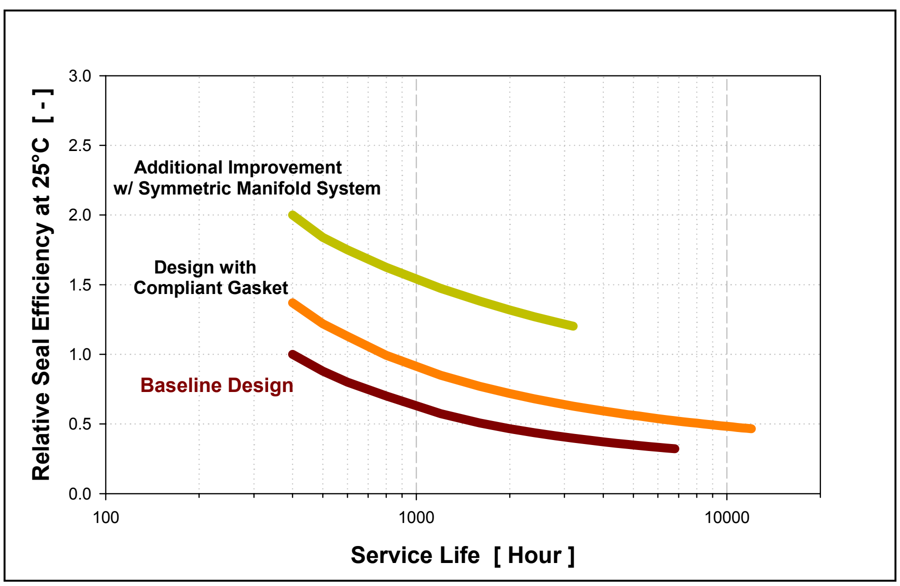

Figure 7. IMPROVEMENT OF GAS-SEALING EFFICIENCY IN SUBSCALE STACKS WITH ADVANCED GASKET AND MANIFOLD DESIGNS:
Significant Improvement of Gas-Seals Verified

Verification of the MW-Class Stack Module

Conditioning and performance testing of a MW module was successfully completed. As reported in the previous semiannual report (Ref. 4), a 1 MW plant was commissioned at the Torrington manufacturing facility to verify performance of the MW power plant design. The MW-class stack module was operated at the rated load at Torrington using the pipeline natural gas fuel. The electricity produced was delivered to the local 480V grid. Figure 8 shows the MW-class module in performance test in Torrington. The MW-class stack and module designs have been verified through one month of testing. The stacks within the module were connected in parallel both electrically and for gas flows. Performance of all the stacks was quite uniform, within ±2.5% as shown in Figure 9.

Figure 8. MW-CLASS MODULE PERFORMANCE TESTING AT TORRINGTON FACILITY:
Operation at Rated Load, on Natural Gas, Verified

Uniform gas distribution through the stacks is a pre-requisite for electrical performance uniformity. Stack to stack gas flow distribution within the module is controlled by flow path resistance, entrance and exit effects and temperature variations of the internal hardware. FCE utilized a detailed Computational Fluid Dynamics (CFD) model to analyze and optimize the internal flow hydrodynamics considering flow parameters and heat transfer with internal hardware. The computational model only analyzed half of the module taking advantage of the symmetry of the module with respect to feed and exit pipes as well as the stack layout. One important parameter for stack flow uniformity and hence the performance is the oxidant inlet temperature profile along the stack face. The CFD model was used to predict the inlet gas temperature profiles for the stacks. Figure 10 shows the oxidant flow velocity vectors within M10-1 module (half) predicting only 0.6% oxidant flow variation between the stacks. The corresponding temperature profiles along the oxidant inlet face are compared with the operational data in Table 3. The observed temperatures agree very well with the CFD model predictions.

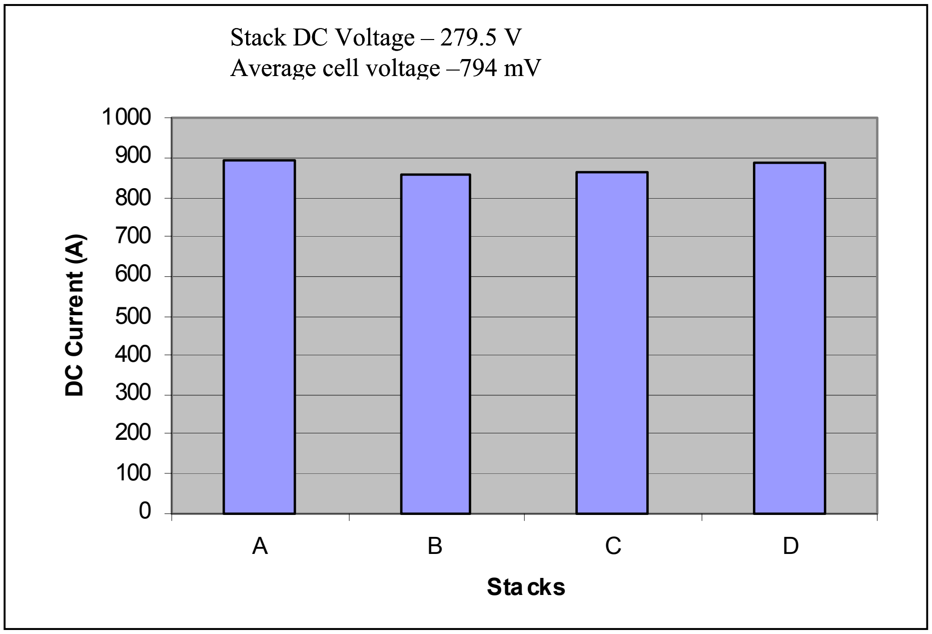

Figure 9. MW-CLASS MODULE PERFORMANCE AT RATED OPERATION:
Stack to Stack Performance Variation in M10-1 is within ±2.5%

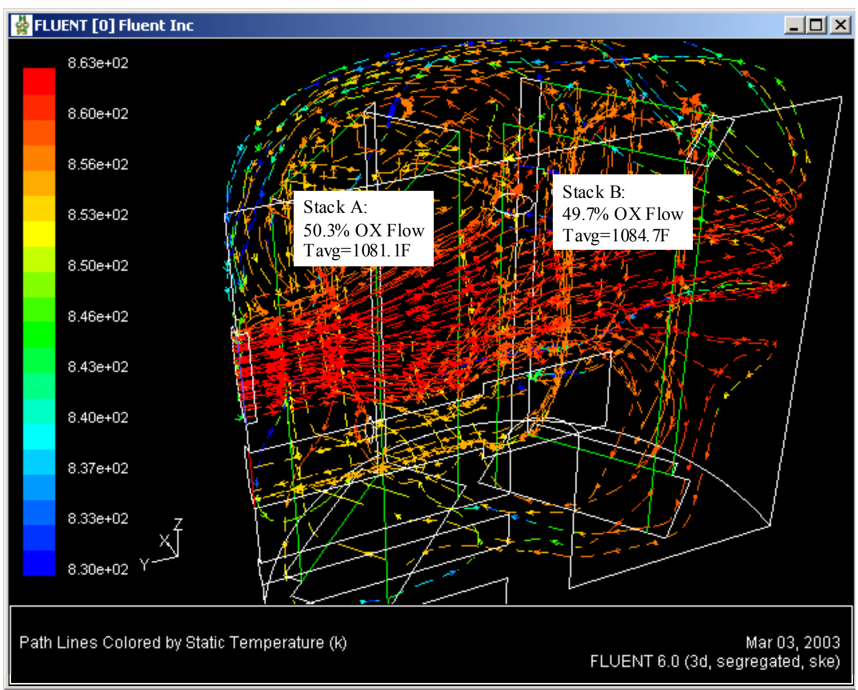

Figure 10. CFD MODEL PREDICTED OXIDANT FLOW VECTORS WITH M10-1 MODULE:
Only ±0.6% Stack-to-Stack Flow Variation is Predicted

Table 3. COMPARISON OF CFD MODEL PREDICTED AND MEASURED TEMPERATURES ALONG THE OXIDANT INLET FACE:
Good Agreement with Model

Temperature Location/Avg.	Stack A		Stack B	
	CFD Prediction (°F)	Operation (°F)	CFD Prediction (°F)	Operation (°F)
top	1086	1086	1090	1092
mid	1088	1089	1090	1093
bot	1081	1081	1082	1082
avg	1081	1082	1085	1087

Balance of Plant Equipment Development

The DFC® power plant uses a sorbent-based room temperature natural gas (NG) clean-up system for sulfur removal from raw fuel. Advanced sorbents for NG desulfurization are being evaluated in the 400 kW facility in conjunction with full-size stack tests. Different materials have been tested. A new design has provided bed life 6 to 8 times that of the baseline sorbent, based on capacity to <100 ppb sulfur breakthrough. The most promising design has been implemented in the standard product design. Evaluation of new lower cost sorbents will continue.

Three inverter vendors, in competition with FCE's initial supplier have been qualified based on tests conducted in the 400 kW facility. The qualification testing characterized inverters in terms of efficiency, reliability, communications, functionality, and island mode operations. Selection from the multiple vendors has resulted in a 50% cost reduction for the inverter with performance equal to or better than the initial inverter units.
The DFC® power plant is considered for secure power applications where it will be able to supply power in the event the grid power is interrupted as well as the primary fuel supply is interrupted. Propane is considered a backup feed for the DFC® power plants for the secure power application. It has been demonstrated that propane can be easily prereformed to fuel cell useable fuel.

Cost Reduction

In an effort to improve the economics of its DFC® products, FuelCell Energy, Inc. (FCE) in pursuing a value engineering activity. The scope of the task includes all parts of the products including the fuel cell stack, stack module, the balance of plant equipment, power plant integration as well as the operation costs. As a result of the focused efforts on all aspects of the power plant costs, FCE has realized ~15% reduction of its submegawatt power plant DFC300 product overall cost over the last six months of 2003. A relative breakdown of the cost reductions in different areas of the product is shown in Figure 11. As can be seen stack module, electrical balance of plant, and mechanical balance of plant contributed to 18%, 12%, and 70% cost reductions, respectively. Value engineering efforts aiming at further cost reductions of the product will continue.

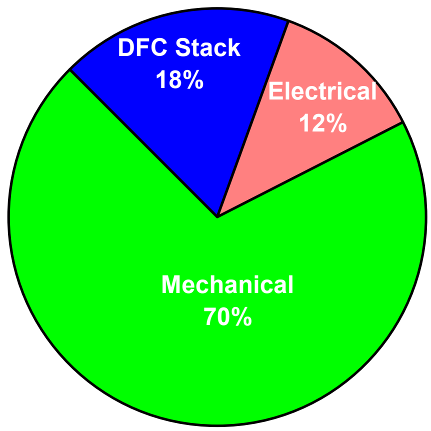

Figure 11. DFC300 PRODUCT COST REDUCTION:
Mechanical Balance of Plant Provided Two-thirds of the Cost Reduction
Realized in the 2nd Half of 2003

5.0 CONCLUSION

The current program has met its planned major milestones to date. Under this program, FCE has scaled up the technology to full-size and developed DFC® stack and BOP equipment technology to meet power plant requirements, and acquired high rate manufacturing capabilities to reduce cost. FCE has developed 50 MW per year manufacturing capability. FCE has designed submegawatt (DFC300A) and megawatt (DFC1500 and DFC3000) class fuel cell power plants and conducted several field trials of the submegawatt design in the US, Europe and Asia. Accomplishments to date include 20 million kWh of electriclity generated at customer sites throughout the world, up to 47% electrical efficiency and up to 80% efficiency in cogeneration application. The field trial experience is being used to gain market experience, identify and resolve field issues, and improve power plant features. Sales and service organization for FCE power plants has been established. Foundation for large, high efficiency fossil fuel based carbonate fuel cell plants for Vision 21 program also has been developed under this program.

Major activities remaining to be completed include: (1) completion of Stack FA-100-3 test and full-size stack design improvement based on the test results, (2) power plant cost reduction efforts leading to 10% further reduction, and (3) materials work for further DFC® life extension.

6.0 REFERENCES

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